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Climate changes caused by degassing of sediments during the emplacement of large igneous provinces: REPLY

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We are grateful to Grzegorz Racki for his comment on our manuscript and for his overall support for the hypothesis that the nature of the rocks in the substrate of large igneous province has an important influence on their environmental impact (Ganino and Arndt, 2009). His principle reservation is that we have oversimplified the situation and have failed to take into account other contributing factors. To a large extent we agree entirely with him: a large number of different processes come into play during the emplacement of an enormous volume of hot magma into heterogeneous crustal rocks, and any attempt to quantify rigorously the total impact must take all of these into account. Indeed, in addition to the factors that he discusses, variations in magma flux through the duration of the eruption (Chenet et al. 2008), and variations in sea-level, the composition and temperature of the atmosphere, and the configuration of the continents may enhance or mitigate the impact of the eruptions. In a four-page *Geology* paper it is impossible to discuss such processes in any detail but we are continuing our studies of aureoles and will treat many of the factors that Grzegorz Racki raises in a forthcoming publication.

In response to his specific points:

1. *Eruptive gas content of basaltic magma.* It is true that basaltic magma contains magmatic gas, including CO₂, SO₂ and halogens, that will be liberated on eruption (Self et al., 2006). But given that the composition of the dominant tholeiitic basalts are similar in every continental province (e.g. Bryan and Ernst, 2008), the contribution of magmatic gases will be similar in each case and their volume will depend mostly on the volume of emitted magma. The very different environmental impact from province to province without correlation with the emitted volume of magma made us propose another cause.

2. *LIP-associated explosive volcanism.* It is true that explosive alkaline magmas, or felsic pyroclastic rocks will emit a greater proportion of magmatic gas than gas-poor tholeiitic basalt, but in most provinces the proportion of such rocks is small compared to that of the tholeiites (Bryan and Ernst, 2008). In addition some provinces with an unusually large proportion of alkaline lavas or felsic ignimbrites have had only a minimal environmental impact. Two notable examples are the Ethiopian (e.g. Keiffer et al. 2004) and Karoo provinces (Erlank, 1984).

3. *Oceanographic consequences of high-latitude volcanism.* The enhanced circulation in the atmosphere of volcanic emissions at high latitudes are well known and these no doubt

contributed to the impact of Siberian flood volcanism (Racki and Wignall, 2005). We are grateful to Grzegorz Racki for additional consequences of eruption at high latitudes. Yet we, like many other authors maintain that the devastating consequences of the Siberian eruption were mainly the result of liberation of toxic gases from contact aureoles in the hydrocarbon-bearing carbonates and evaporates of the sedimentary basin beneath this province (Retallack and Jahren, 2008 ; Svensen et al. 2008).

To conclude, we agree with Grzegorz Racki that the contribution of each of these factors must be taken into account and that the case history of LIP emplacement should be treated on a case-by-case basis.

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